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A Cognitive Agent for Spectrum Monitoring and Informed Spectrum Access

by Jerry L Silvious

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14. ABSTRACT
This report presents a cognitive approach to addressing spectrum monitoring and access. A cognitive software agent was written in MATLAB to demonstrate some basic capabilities of a cognitive architecture, namely, sensing, analysis, learning, short- and long-term memory, problem solving, decision making, and focus of attention. The goal of the cognitive agent was to mimic intelligent behavior with respect to spectrum access.

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1. Background

The US Army Research Laboratory (ARL) is investigating the characteristics of electromagnetic environments (EMEs) to understand what spectrum bands are accessed, when those bands are accessed, and how much energy is detectable in each band. Knowledge of how the spectrum is being accessed can assist current and future radio frequency (RF) systems by decreasing the probability of concurrent access and increasing the probability of informed shared access. Similarly, knowledge of spectrum usage is required if the objective is to degrade or deny access to the spectrum.

This report presents a cognitive approach to addressing spectrum monitoring and access. A cognitive software agent was written in MATLAB to demonstrate some basic capabilities of a cognitive architecture, namely, sensing, analysis, learning, short- and long-term memory, problem solving, decision making, and focus of attention.[1] The goal of the cognitive agent was to mimic intelligent behavior with respect to spectrum access.

2. Introduction

Many types of cognitive architectures have been investigated to model various aspects of human cognition.[2] Some models attempt to emulate the reaction time of humans, while others place more emphasis on models of human memory creation and recall. The cognitive agent in this report uses the second approach. The knowledge domain of the cognitive agent is the electromagnetic spectrum.

The maturity of a cognitive agent can be characterized by the robustness of the agent's Depth of Knowledge (DOK) Levels.[3] DOK Level 1 includes general abilities to measure, tabulate, and report observables. DOK Level 2 involves analyzing the observables, displaying graphs, and classifying patterns. DOK Level 3 involves learning the recognized patterns by creating short-term memories; high-value patterns are subsequently stored into long-term memories. DOK Level 4 involves extended reasoning by applying concepts, conducting active experimentation, and adapting future behaviors based on results.

This report explains in more detail how each DOK Level is implemented: how the agent passively senses and learns about the EME, creates short- and long-term memories, and behaves when presented with an objective to actively access the spectrum.

3. Cognitive Agent Methods

3.1 DOK Level 1: Sensing

The agent "senses", or acquires information about, the RF spectrum by collecting real-time samples of the spectrum via an antenna and digitizing hardware or stored samples from a previously digitized spectrum.

Figure 1 is a typical very high frequency (VHF) spectrum spanning 30 to 300 MHz. The darker shades represent higher power densities.

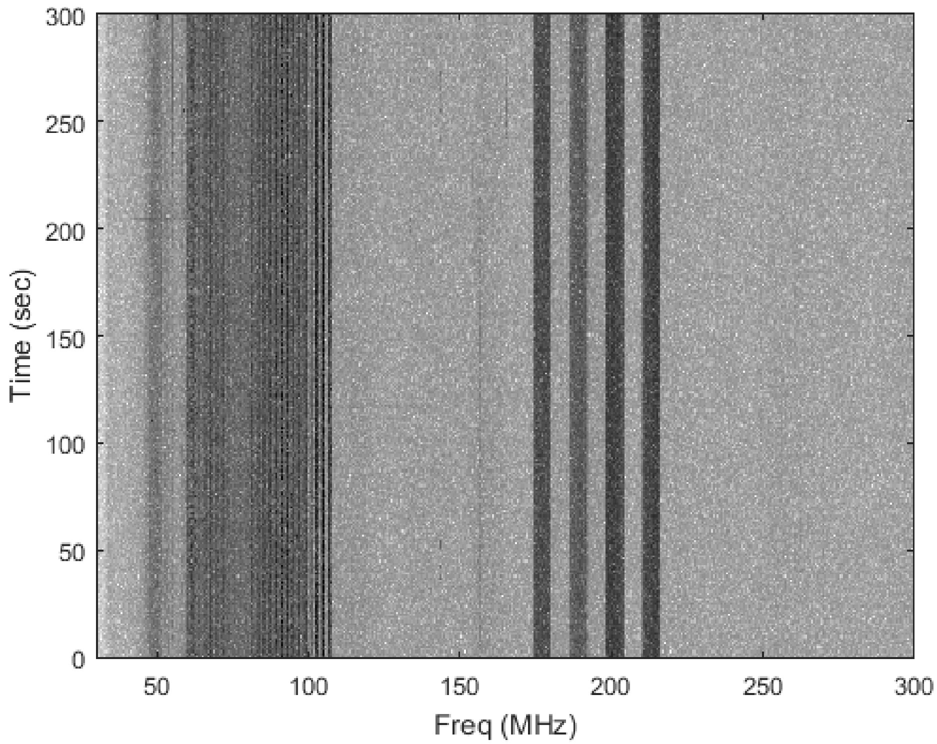

Fig. 1 Typical VHF spectrum

3.2 DOK Level 2: Analyzing

The agent analyzes how the energy is distributed within the spectrum by dividing the frequencies into channels. Given a priori knowledge of how channels are used by specific users, the agent may classify these channels, for instance, as frequency modulated (FM) radio stations, digital television (DTV) stations, or cellphone channels. These persistently occupied channels may then be associated with primary licensed users.

For instance, the dark vertical bands between 88 and 108 MHz in Fig. 1 are indicative of FM radio stations. These stations are separated by 0.2 MHz. The vertical bands between 174 and 216 MHz are DTV stations. Specifically, RF channels 7 (174 MHz), 9 (186 MHz), 13 (198 MHz), and 15 (210 MHz) are clearly observable. DTV stations are allocated 6 MHz of bandwidth. The pilot tone that enables a receiver to reliably detect the presence of a DTV station is offset from the channel frequency by 0.310 MHz. Broadcasting channels that are discovered can be further identified using Internet resources that provide call signs and geographic locations of licensed transmitters.[4]

For a modest length (N > 500) sequence of random numbers drawn from the standard uniform distribution on the open interval (0,1), the mean of the first lag of the normalized autocorrelation function (ACF) is approximately 0.75, with a standard deviation of 0.02. Figure 2 shows the probability density function of the ACF. Sequences with an ACF greater than 0.9 are indicative of low variability, typical of continuous tones, such as a DTV pilot tone. ACF values less than 0.6 are typical of FM stations and pulsed transmitters. The ACF is an effective technique for characterizing frequency channels as low variability, amplitude modulated, or random noise channels.

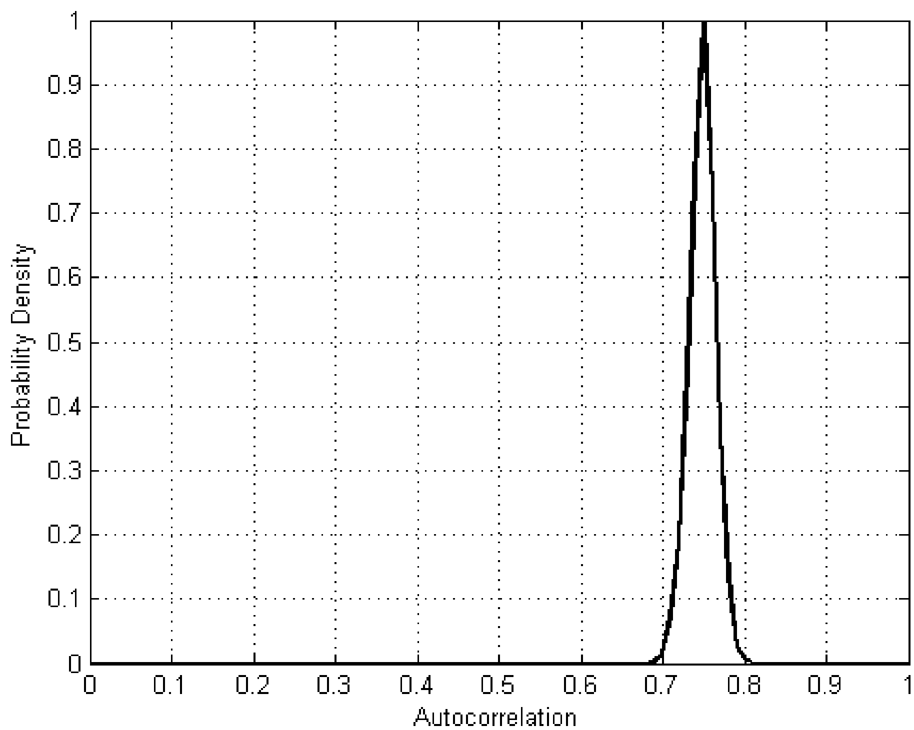

Fig. 2 Probability density of the ACF of a uniform random distribution

Figure 3 shows the ACF of the frequency channels of the typical VHF spectrum in Fig. 1. A plot of the median power versus ACF of the channel samples is shown in Fig. 4. The probability that a given channel is noise, intermittent, or a constant tone is directly assignable. Power levels below –55 dBm in Fig. 4 are due to the lower gain of the antenna below 35 MHz.

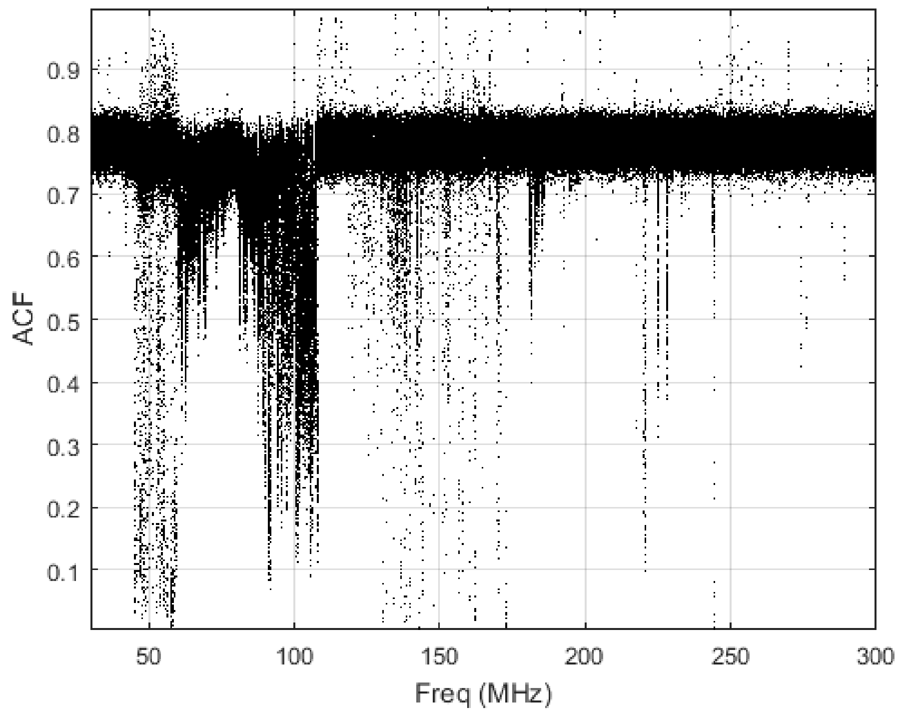

Fig. 3 ACF of a typical VHF spectrum

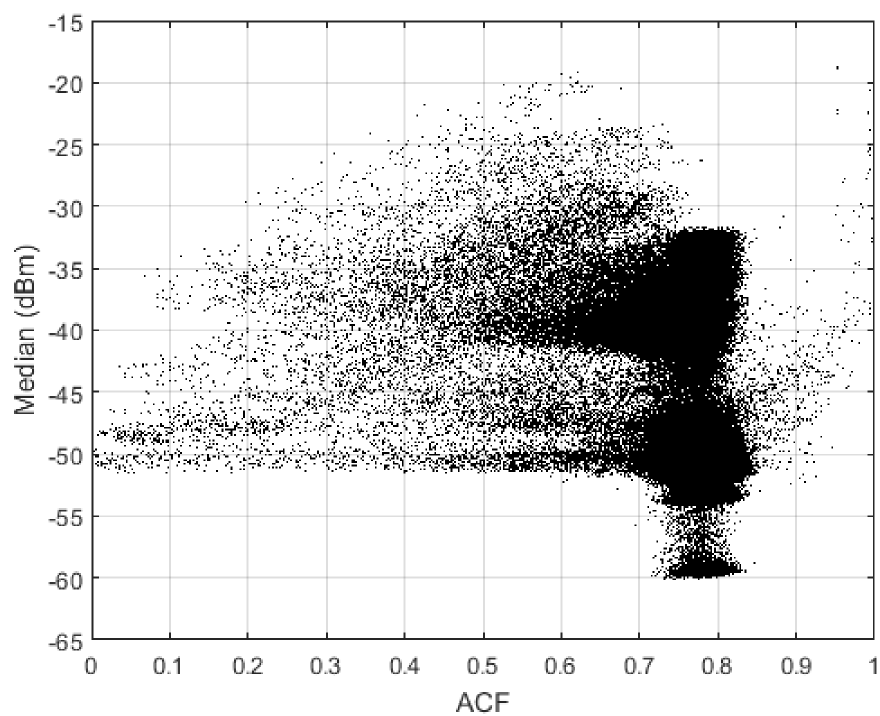

Fig. 4 Median power vs. ACF of a typical VHF spectrum

Note that the ACF can be used to detect signals over a broad range of power levels. Figure 5 shows the dependence of the ACF on the signal-to-noise ratio. A constant signal level was added to a uniform distribution to compute the ACF.

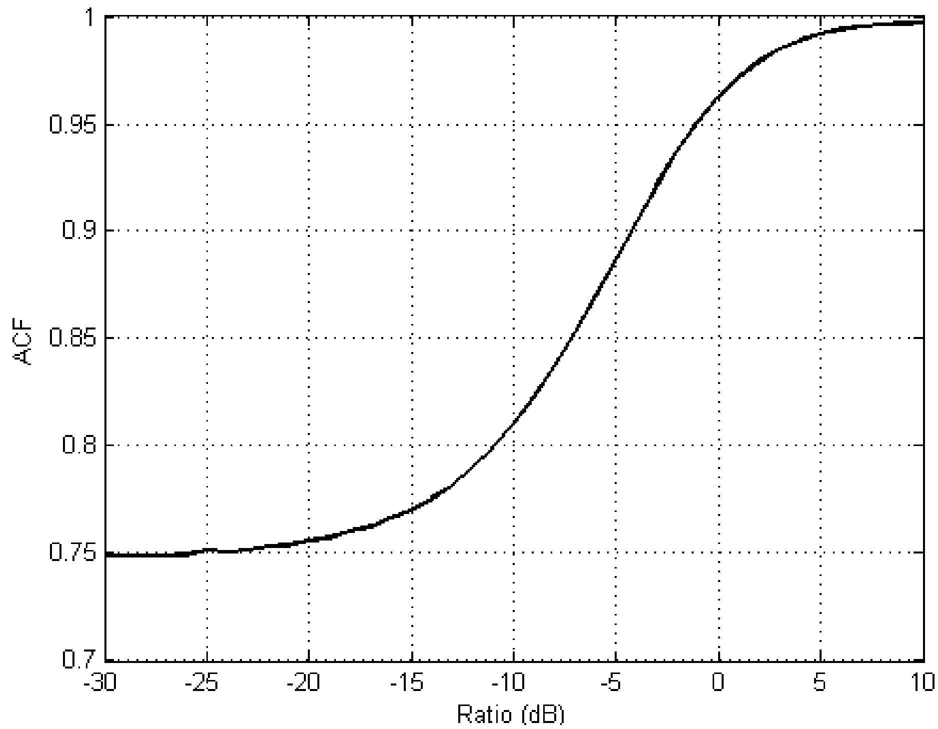

Fig. 5 ACF vs. the ratio of a constant signal added to a uniform random distribution

3.3 DOK Level 3: Learning and Short- and Long-Term Memories

A short-term memory of the current spectrum state and identified users can be created by saving the state of the agent to a temporary file. High-value, long-term memories written to more permanent files may consist of geo-locations of identified primary users, other channels that have persistence, and temporal characteristics of the power received in the channel.

3.4 DOK Level 4: Focus of Attention, Problem Solving, and Decision Making

When the agent is operating in a cooperative mode, solutions must be found that minimize concurrent spectrum access. When the agent is operating in a spectrum denial mode, efficient jamming measures must be found. The agent accomplishes these tasks by focusing attention on the spectral bands best suited for the objective, analyzing the channel for received signal strength, calculating probability of active users using the ACF, and adapting to temporal availability.

Federal Communications Commission regulations assign frequencies to be used for specific purposes. These assignments were incorporated into the agent's knowledge base for this study. The role of the cognitive RF system (Federal, amateur, radio navigation, etc.) will influence which frequency channels occupy the focus of attention of the cognitive agent.

3.5 Behaviors: Adaptation and EME Modification

The cognitive agent may be embedded in a larger RF system that must change state to accommodate a changing EME. In a cooperative scenario, the cognitive agent may recommend a simple change in operating frequency by selecting a channel that has a low power density and noise-like ACF. The cognitive agent would then monitor the response of the EME to this change in frequency. If no other users are detected on that channel, the RF system may continue to use that frequency. The RF system may also actively probe the EME to see if active users vacate a channel in a cooperative manner.

The cognitive agent may have to adapt to a contested EME in which a jammer is operating. A change in operating frequency may be the easiest countermeasure for a jammer operating in spot jam mode, in which a single frequency channel is degraded. The cognitive agent may also exploit temporal vacancies in the EME if the jammer is discovered to be operating on a predictable time schedule.

A knowledgeable cognitive agent can mimic intelligent behavior in a frequency-swept, jammed EME by searching for a pattern in the swept frequencies. Depending on the capabilities and processing requirements of the RF system, the cognitive agent may recommend a frequency-use pattern that avoids the changing jammed frequencies.

In a barrage jammer EME, in which wideband jamming is occurring, the cognitive agent may recommend a frequency band outside the jammed frequencies. If the cognitive agent is purposefully acting as the jamming agent, an analysis of the emitters in the EME becomes indispensable to efficiently degrade the EME. Figure 6 shows a VHF spectrum in a barrage jammer EME. Note the elevated noise levels in the FM and DTV frequency bands. Figure 7 shows the ACF of the Fig. 6 jammed spectrum. The low ACF values around 160 and 270 MHz result from the pulsed signals shown in Fig. 6.

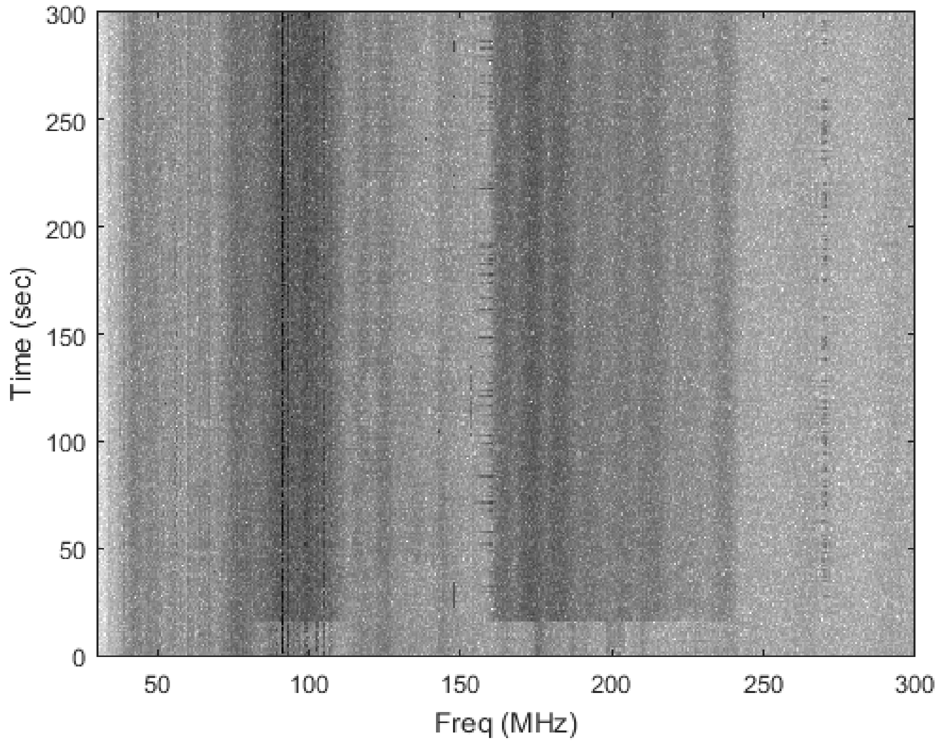

Fig. 6 Barrage jamming of the VHF spectrum

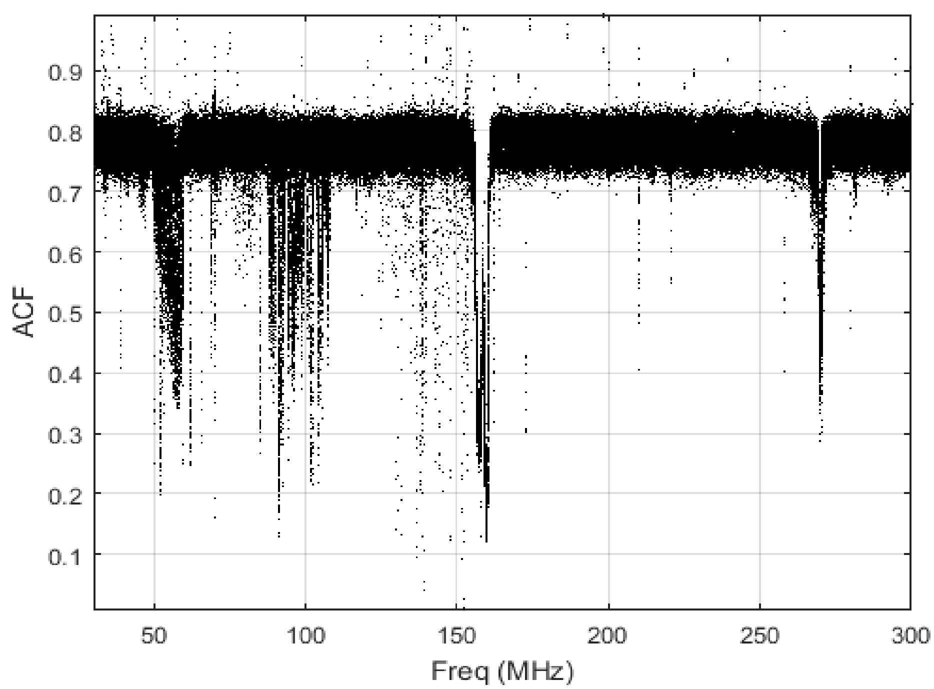

Fig. 7 ACF of the jammed VHF spectrum

Figure 8 is a plot of the typical ACF shown in Fig. 3 versus the jammed ACF shown in Fig. 9. While a majority of the channels are still noise-like, many channels in the typical spectrum that had previously been categorized as modulated have also become noise-like. The frequencies that persisted with ACFs greater than 0.9, despite the jamming, are the DTV pilot tones.

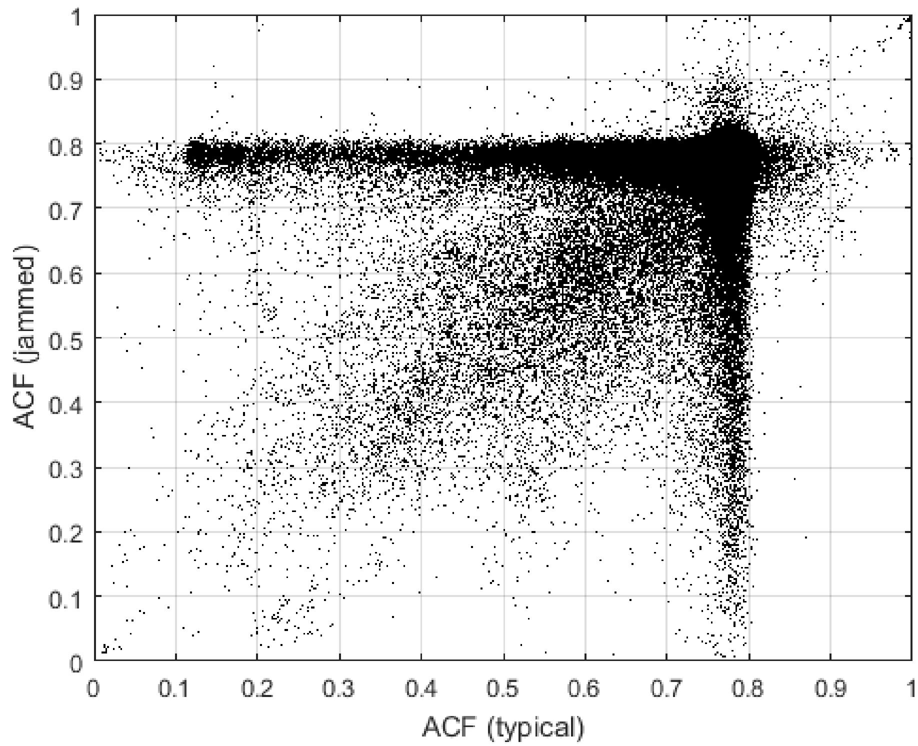

Fig. 8 The ACF of a typical spectrum vs. the ACF of a jammed spectrum

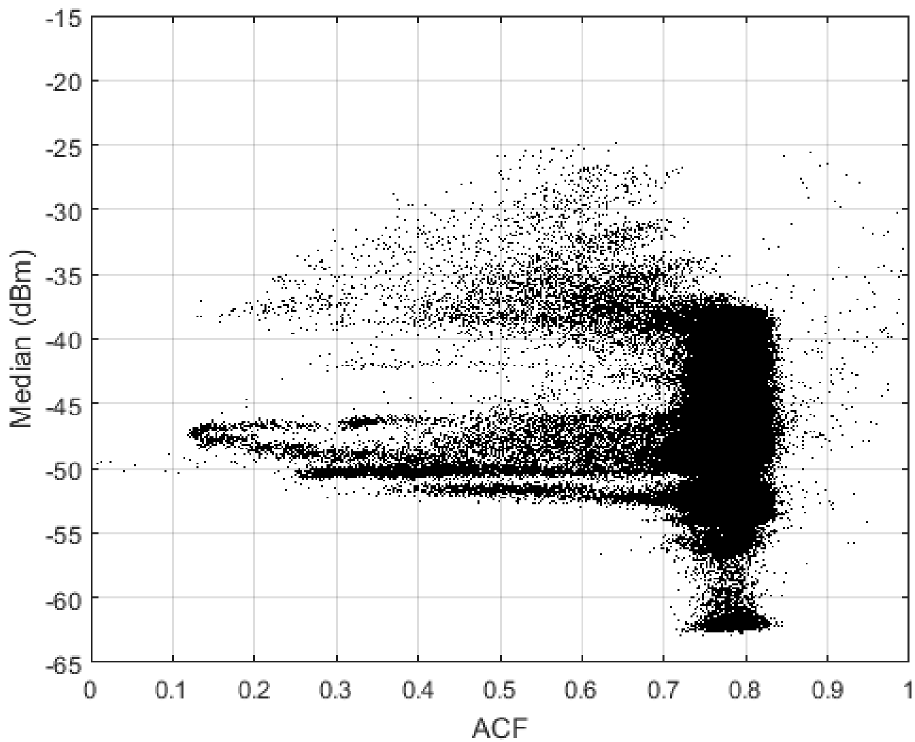

Fig. 9 Median power vs. the ACF of the jammed spectrum

4. Results and Discussion

A cognitive architecture approach to accessing the spectrum provides a more flexible means to meet the objectives of future RF systems. By incorporating elements that mimic human sensing, learning, memory, and decision making, a cognitive agent can assist in meeting those objectives.

The cognitive agent in this report has shown that, after sensing the spectrum and analyzing the time-history of the power levels, the ACF effectively separated spectrum frequencies into 3 categories: low-variability tones, modulated tones, and noise. These categories could aid the cognitive agent in recommending which frequencies to select to best meet the objectives of the RF system.

The cognitive agent also demonstrated that the ACF and median power level can be analyzed to learn patterns in the EME. High-value patterns, such as the frequency channels that are consistently noise-like, provided a long-term memory to assist in making dependable decisions regarding spectrum access.

5. Conclusions

A software agent was written in MATLAB to investigate whether a cognitive-based approach can improve spectrum monitoring and access by RF systems. The agent was designed to demonstrate the ability to passively sense the EME, learn about channel occupancy, and create short- and long-term memories of the EME. The agent also made decisions about actively accessing the EME by adapting to the EME or attempting to modify the EME to meet objectives.

Given these cognitive capabilities, a cognitive agent should enable an RF system to make better informed decisions regarding access to the spectrum.

6. References and Notes

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List of Abbreviations and Acronyms

ACF	autocorrelation function
ARL	US Army Research Laboratory
DOK	Depth of Knowledge
DTV	digital television
EME	electromagnetic environments
FM	frequency modulated
RF	radio frequency
VHF	very high frequency

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